

AMENDMENTS TO THE SPECIFICATION:

Page 1, immediately preceding the paragraph commencing “This invention relates to ad hoc networking...” insert the following heading and sub-heading:

BACKGROUND

1. Technical Field

Page 1, amend the 1st paragraph as follows:

This invention relates to ad hoc networking applications, in which a number of communications devices co-operate to form a communications network.

2. Related Art

There are two basic types of ad hoc networking, namely many-to-many communication, wherein the devices communicate mainly between themselves, and ad hoc edge networking, wherein the devices interface with conventional fixed networks through interface or edge devices. The communications devices form devices of a wireless network, allowing data to be relayed from an originating communications device to a destination communications device, by way of other communications devices. Such devices have a number of applications in circumstances where the communications devices are likely to be moving in unpredictable ways. A particular application scenario is a sensor network, in which data is collected from a network of mobile sensor devices, each of which is capable of taking measurements and relaying

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packets of data. Such devices are used by scientists taking measurements of the behaviour of the atmosphere, the sea, ice caps, lava flows or wildlife. The environments in which such devices are required to operate often have measurement points widely dispersed in both space and time. Some of the environments are hostile to human life. In some applications, such as the study of animal behaviour, human intervention could compromise the data. For these reasons the devices must be capable of operating autonomously, and transmitting the data they collect to a more convenient point using a wireless medium such as radio or sonar. Moreover it is not usually possible to provide a continuous power supply, so the useful life of a device is primarily constrained by battery life.

Pages 3-4, bridging paragraph:

A number of lightweight ad hoc routing protocols have been proposed. The work by Toh already discussed describes a wireless communication network, and a scheme to maximise the battery life of ad hoc devices in the network. S Singh, M Woo and C Raghavendra, have made a detailed study of power-conservation in ad hoc networks at the MAC and network layers ("Power-Aware Routing in Mobile Ad hoc Networks". Proceedings of the Fourth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), (Dallas, TX, Oct. 1998)). They include schemes for devices to power-down in between expected transmissions, and they take

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into account device load as an important factor in power consumption. Their main concern is to prevent network partitioning when gaps appear in the network as a result of devices running out of battery power. Work by WB Heinzelman, AP Chandrakasan and H Balakrishnan considers sensor networks specifically. ("Energy-Efficient Routing Protocols for Wireless Microsensor Networks", Proceedings of the 33rd International Conference on System Sciences (HICSS '00), January 2000.)[[.]] This work assumes variable device broadcast range. Their focus is on the use of clustering techniques to reduce bandwidth usage by, for example, data aggregation of similar data, and using predictable transmission times, co-ordinated by the cluster heads. This approach saves significant energy, compared with an always-on approach, but the routing side is simplistic and not fully developed. In particular, their experimental scenario assumes the devices could all broadcast to the base station if they chose to do so, which would not be realistic, in general, for sensor network applications. Work by A Cerpa, J [[elson]] Elson, D Estrin, L Girod, M Hamilton and J Zhao, refers to habitat monitoring as a driver for wireless communications technology, and focuses on power-saving by having devices switching themselves on and off according to whether they are in the vicinity of regions where interesting activity is expected, or detected by other devices. ("Habitat Monitoring: Application Driver for Wireless Communications Technology", ACM SIGCOMM Workshop on Data Communications in Latin America and the Caribbean, Costa Rica, April 2001.) Work by Y. Xu, J. Heidemann, and D. Estrin again

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focuses on using ~~powered-down~~ powered-down modes for devices to conserve power, based on whether payload data is predicted or not, and on the number of equivalent devices nearby that could be used for alternate routing paths. (“Adaptive energy-conserving routing for multihop ad hoc networks”, Tech. Rep. 527, USC/Information Sciences Institute, Oct. 2000.) The assumption here is that the underlying routing will be based on conventional ad hoc routing protocols such as the AODV system already discussed. Sensor networks, however, typically would require a lighter weight approach to routing, where decisions are based on information from immediate neighbours only, and this knowledge needs to be conveyed succinctly, ideally as part of the packet headers for the actual data to be collected.

Page 5, immediately preceding the paragraph commencing “The wireless relay devices therefore define...” insert the following heading:

BRIEF SUMMARY

Page 8, immediately preceding the paragraph commencing “An embodiment of the invention...” insert the following heading:

BRIEF SUMMARY OF THE DRAWINGS

Page 8, immediately preceding the paragraph commencing “Figure 1 shows a device 20...” insert the following heading:

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Pages 8-9, bridging paragraph:

Figure 1 shows a device 20 according to the invention. It comprises a wireless transmitter 21 and a wireless receiver 22, and data collection means 23 which include position sensors, and environmental or physiological sensors for determining properties of the environment of the device, or of some object to which it is attached. There is also a data buffer 24 for storing payload data (that is to say, data that is to be transmitted to a destination for processing) and a data store 25 for operational data (that is to say, data required for the ~~operation~~ operation of the device and in particular for controlling the transmission of the payload data). There is also computation means 26 for processing the data collected by the data collection means 23 and stored in the data buffer 24, and control means 27 for controlling the operation of the device in response to outputs from the computation means 26. The device is powered by a battery 28 whose condition is monitored and the results stored in the data store 25 with other operating parameters. The power connections themselves are not depicted in this schematic diagram[[]]).

Page 9, 1st full paragraph:

Figure 2 shows a network comprising several devices 10, 20, 30, 40, 50, 60, 70, 80, each of the type shown in Figure 1. These devices are free to move relative to each other through their environment, collecting data from their environment such as temperature, barometric pressure, salinity, etc[()]]. This network of sensors is low-cost and can hence be haphazardly distributed in previously difficult to monitor areas. They may be carried by inanimate forces such as ocean or air currents, lava or glacier flows, or they may be attached to animals or human beings to monitor their movements or physiology, or to a vehicle to monitor its progress on a journey or to locate it if it is reported to have been stolen.

Page 9, 2nd full paragraph:

The devices 10, 20, 30, 40, etc shown in Figure 2 form an ad hoc wireless network 19, 29, 39, 49, etc. The wireless connections may use radio, sonar or any other transmission medium suitable for the environment in which the devices are expected to operate. Data collected by a device 20 (either by its own sensors 23, or relayed from another device 10) is transmitted to a destination 90 either directly or by means of one or more other devices 30. These other devices may also collect data. The destination 90 is a fixed receiver station, which will be referred to as an information "sink", and which collects data collected by the mobile terminals 10, 20, 30, etc for

subsequent processing. There may be more than one sink in the network. The sink device 90 is more powerful than the sensor devices 10, 20, 30, etc, both in terms of processing capability and power-consumption, and either have long-term storage facilities for the data, or a long-range transmission link 98 to a data-processing centre 99. The sensor equipped devices 10, 20, 30 themselves have very limited battery power (allowing only short-range wireless transmissions), small processors and limited memory.

Pages 9-10, bridging paragraph:

The sensors accumulate data for a period of time in a 'low-power' consumption mode 31 before powering-up (32) to determine if data needs to be transmitted ([[33,34]] 33, 34), transmitting the data if appropriate (35), and then powering-down (36) for another period of data collection (31). The power-up (transmission) time can therefore be small in comparison to the power-down (sensing) time. In the preferred arrangement, all devices synchronise the parameter-determination stage [[33,34]] 33, 34 as they need to exchange status data (step 34). However, having exchanged the status data, it is desirable that not all devices will transmit payload data simultaneously (step 35) to avoid interference problems that may occur, particularly if two devices (e.g. [[10,40]] 10, 40 in Figure 2) are ~~transmitting~~ transmitting to the same device 30. Since each stage 31, 32, 33, 34, 35, 36 of the cycle is much longer than the individual

transmission periods within each stage, this is readily achievable. The three-stage cycle is as follows:

Page 10, paragraph commencing at line 16:

The sensing stage could be considerably longer than the other stages. This maximises the sensors' battery life by operating in a low power consumption mode for as much of the time as is possible. This assumes that devices can synchronise their power-up times. Alternatively, devices can be in a listening mode during power-down time, in which they can receive both payload and status data from other devices, but will not transmit.

Page 11, paragraph commencing at line 13:

• Buffer size N_i a scalar quantity representing the amount of data awaiting transmission, expressed as a fraction of the total capacity of the buffer 24.

Page 11, paragraph commencing at line 16:

• Battery charge remaining, B_i a scalar quantity representing the expected life of the device. As the devices 10, 20, etc move around, the wireless links 19, 29, 39, etc between them have to be re-arranged in order to provide the optimum network. As well as physical location, factors such as the spare capacity of the buffer store 24 and the

battery 28 are taken into account in determining whether a wireless link 29 should be established between two devices 20, 30. The process by which this is done will be described in detail shortly.

Page 11, paragraph commencing at line 24:

• Unit cost of forwarding C, which is determined at the end of the previous cycle (step 400) and is taken to be the cost in battery power per packet that would have been incurred the last time a suitable destination for a packet was found. This measure is used regardless of whether or not the packet was actually sent – for example there may have been insufficient battery power to transmit the packet to that destination. It should also be noted that the devices are mobile, so the actual cost of forwarding may be different from this historic estimate.

Page 11, line 25:

where N = number of packets of data currently in buffer₁

Page 12, 1st three lines:

B = battery level₁

C = cost of forwarding one packet[[.]], and

k = a small constant whose function will be described shortly₁

Page 12, paragraph commencing at line 7:

Consequently, if a device would just be able to send all of the data in its buffer to a suitable neighbour ($B/C = N$) then it will have a status value $h=1+k/N$. A threshold value is set at this value, or slightly lower to ensure the device is not completely drained. This threshold value will be referred to below as "M". Since the value of k is small, it is convenient to set $M=1$.

Page 14, paragraph commencing at line 12:

This value U is a measure of the time-sensitiveness of the data in the transmission process, and hence the speed with which it is to be returned to the sinks. It is assumed the sensors are mobile. At the beginning of the experiment (when t/T has a low value), it is preferable to wait for sensors that are a long way from a sink to move around so that data collected by such sensors is not transmitted a long distance through the network, draining network resources. ~~Towards~~ Towards the end of the experiment, however, any data not transmitted risks being lost altogether, and battery conservation is no longer important.

Page 14, paragraph commencing at line 20:

By varying the value of the exponent “n”, the sensitivity can be adapted to the requirements of the data capture process. If the data is very time-sensitive, and needs to be transmitted back to the sinks soon after being collected, then a small value of n is required (so that U rises to a value of unity very early in the process and therefore almost always exceeds the status values “h”). Similarly, if the buffers of individual sensor devices are small, a small value of n will reduce the number of data packets ‘dropped’ by overfull buffers. If the network collects most of its data at the beginning of the experiment, then a small value of n is superior.

Page 15, 1st paragraph:

Provided the status value h of the target device is less than the value $U[.,.]$ (step 47), the device then forwards up to ten packets of data to the selected neighbouring device (step 48).

Page 15, 2nd paragraph:

This actual cost of transmission is now calculated (step 400) as described above, to supply the value “C” for the next cycle.

Page 15, 3rd paragraph:

When a device 20 has identified a device 30 to which data can be forwarded, it retrieves data from its buffer 24 and transmits it to the target 30. The device 30 then repeats the process of identifying a suitable neighbour and so on, until the data reaches the sink 90. If no suitable device is identified, the data is stored in the buffer 24 until the movements of the devices ~~brings~~ bring a suitable device into range. If a device 20 is cut off from any path to a sink 90, it can simply store any payload data in the buffer 24 until the movements of the devices ~~re-establishes~~ re-establish a feasible route. If the network is sparsely populated, such that devices are widely separated, most data transmissions may only occur when a device 20 comes within direct range of a sink 90. In densely populated networks, paths having a larger number of hops 19, 29, 39 will be more common. The process is flexible enough to cope with a wide range of circumstances, in terms of network topology and device mobility, without such variations requiring special treatment.